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The Influence of Nitrogen and Potassium on the Availability of Fertilizer Phosphorus

L. O. Fine

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The Influence of Nitrogen and Potassium on the Availability of Fertilizer Phosphorus

Agricultural Experiment Stations of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, and Alaska and the United States Department of Agriculture cooperating.

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Authors of this Bulletin

L. O. Fine, with collaboration of F. C. Bauer, A. C. Caldwell, D. L. Grunes, H. R. Haise, L. E. Haley, F. L. Hammers, R. F. Holt, A. Hustrulid, M. L. Jackson, A. Kaufman, F. E. Koehler, L. F. Marriott, J. L. Nelson, A. J. Ohlrogge, and R. H. Yamaga

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This publication is the result of research initiated by the following members of the Phosphorus Work Group of the North Central Soil Research Committee, which preceded the establishment of the Regional Committee NC-16:

Illinois Agricultural Experiment Station—L. E. Haley, Assistant Agronomist; F. C. Bauer, Professor of Soils; J. L. Nelson, Assistant in Soil Fertility.

Indiana Agricultural Experiment Station—A. J. Ohlrogge, Associate Professor of Agronomy.

Minnesota Agricultural Experiment Station—A. C. Caldwell, Associate Professor of Soils; A. Hustrulid, Professor of Agricultural Engineering; F. L. Hammers, Junior Scientist in Soils; R. F. Holt, Assistant Professor of Agronomy (presently, University of Connecticut).

Nebraska Agricultural Experiment Station—F. E. Koehler, Assistant Professor of Agronomy, University of Nebraska, and Soil Scientist (Agent), U. S. Department of Agriculture.

South Dakota Agricultural Experiment Station—L. O. Fine, Professor of Agronomy, South Dakota State College, and Soil Scientist (Agent), U. S. Department of Agriculture.

Wisconsin Agricultural Experiment Station—M. L. Jackson, Professor of Soils; L. F. Marriott, now Assistant Professor of Soil Technology, Pennsylvania State University; A. Kaufman, Assistant in Soils.

U. S. Department of Agriculture—D. L. Grunes, H. R. Haise, and R. H. Yamaga, Soil Scientists, Northern Great Plains Experiment Station, Mandan, North Dakota.

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The Influence of Nitrogen and Potassium On the Availability Of Fertilizer Phosphorus

Lawrence O. Fine

Introduction

The constant pressure on farmers to produce more efficiently and economically has resulted in very rapid expansion of fertilizer usage. Furthermore, the continued shrinkage (estimated to be 10 million acres in the last 10 years) of our arable land acreage because of losses through erosion and diversion to industry and residential uses, military reserves, and highway and recreational purposes, makes efficient production increasingly important as our population expands.

These factors, plus the expense of fertilizer usage and the fact there is a physical limit to our resources of mineral nutrients usable for fertilizer, make the efficient use of fertilizer constituents of prime importance. It was with this in mind that the investigations reported herewith were conducted.

From time to time there have been various isolated experiments reported bearing on the relationship of other fertilizer nutrients to soil and fertilizer phosphate availability. However, the results and conclusions have been somewhat indeterminate, resulting in no clear-cut evaluation of the effects in question. The availability of beta-radiating P_{32} at the close of World War II rendered many of the questions long puzzling soil scientists and plant physiologists amenable to study.

Work has been in progress in some of the states in the north-central region on various aspects of this problem since 1949. In others only 1 or 2 years' work has been done. This publication is the result of a coordinated approach to the problem in seven states represented in the phosphorus subcommittee of the North-Central Soil Research Committee and the Agricultural Research Service of the USDA. The states are Illinois, Indiana, Minnesota, Nebraska, North Dakota, South Dakota, and Wisconsin. The work in North Dakota was conducted by ARS personnel of the USDA.

While the specific objectives and the methods have not been identical in all states, the general objec-

Dr. Fine is Professor of Agronomy at South Dakota State College Agricultural Experiment Station and Soil Scientist (Agent), U. S. Department of Agriculture.

tives were quite similar and can be briefly stated as follows:

1. To make a biological evaluation of the effect of nitrogen and potassium fertilizers added to soils on the availability of fertilizer phosphorus.
2. To study the effect of level of nitrogen and potassium content of the soil on the yield and phosphorus uptake of various crops.
3. To determine the effect of placement of nitrogen and potassium on phosphorus utilization by various crops.
4. To determine the mechanism by which one nutrient may affect the uptake of another nutrient by crops.

Historical Review

A large part of the literature that has accumulated since the advent of the use of radioactive phosphorus has related to the effect of rate, carrier, placement, and soil factors on the utilization of fertilizer phosphate.

Coleman (1), without benefit of radioactive phosphorus, investigated the differential response of cotton and oats to phosphorus on two Mississippi soils. He concluded that the poor response to phosphorus at low nitrogen levels was due to failure of the crops to utilize the phosphorus when inadequately supplied with nitrogen.

Smith, Kapp, and Potts (9) and Smith et al (10) in Texas began studies in 1949 and 1950 on the effect of rates and ratios of N and P_2O_5 on phosphorus uptake by forage plants. Their earlier studies indicated that increasing applications of nitrogen increased the removal of all nutrients in terms of pounds per acre through the effect of nitrogen on yield. The later studies showed that increased nitrogen applications progressively increased the recovery of fertilizer phosphorus by winter oats and that nitrogen applications to crimson clover increased the uptake of fertilizer phosphorus up to 30 pounds of applied nitrogen per acre.

Domby, Stelly, and Sell (2), working in Georgia, reported that increasing nitrogen applications reduced the phosphorus content of oat forage but increased the phosphorus removal per acre as a result of yield differences.

Lorenz and Johnson (5), working with California soils, found that applications of ammonium sulfate greatly increased the yield of crops, which was considered synonymous with increased release of native soil phosphorus. Nitrogen supplied as $Ca(NO_3)_2$ and $NaNO_3$ did not have this effect. Release effected by NH_4NO_3 was intermediate. Acidification of this slightly acid soil with elemental sulfur and addition of large amounts of phosphatic fertilizer resulted in as good response in yield to nitrate N forms as to $(NH_4)_2SO_4$ nitrogen.

More recently, Robertson et al (8) studied the utilization of phosphorus by corn as affected by placement and nitrogen and phosphorus fertilization. As little as 5 pounds of nitrogen per acre as ammonium sulfate in the starter fertilizer increased utilization of fertilizer phosphate by 50 percent at the 12-inch growth stage. Potassium added with phosphorus had little effect on utilization of the latter, and when mixed with the nitrogen - phosphorus starter, decreased the percentage of plant phosphorus derived from the fertilizer as compared to the nitrogen-phosphorus starter.

Regarding placement effects, early utilization was greatest when fertilizer bands were placed at the seed level. However, greatest total utilization over the season resulted from a combination of side-placed starter application and a 6-inch deep application of 60 pounds of P_2O_5 per acre in bands 14 inches apart the day before planting.

Scope and Methods

The data reported in this bulletin are from several field and greenhouse experiments conducted in the seven states mentioned.

The tabulation below indicates location and nature of experiments conducted on the various crops:

The general technique was to grow the crop or crops concerned in a factorial type experiment with one or several rates of phosphate and all of the nitrogen and/or potassium rates in combination with each phosphate rate.

In all experiments with row crops the fertilizer was banded. An exception was in Nebraska where the phosphate was broadcast with the nitrogen or potassium applied in a single band with phosphate, or in a separate band on the opposite side of the row in cases where physical admixture was a variable.

In some of the experiments with oats, all the fertilizer was drilled with the seed; in others, the nitrogen and/or potassium was broadcast and the phosphate was applied in rows, either with the seed or between drill rows. The machine most commonly used is the combination fertilizer-seeder illustrated in figure 1.

In all cases where the effect of joint application of nitrogen and/or potassium with phosphorus or of

State	Crops	Number of Experiments	Type of Experiments
Illinois	Oats	2	Factorial N + K on P (field)
Indiana	Corn	2	N sources and rates, factorial on P, also placement of N + K (field)
Minnesota	Corn	1	N + K factorial on P (field)
	Corn	1	N + K factorial on P (greenhouse)
	Oats	1	N + K factorial on P (greenhouse)
	Alfalfa	1	N + K factorial on P (greenhouse)
Nebraska	Oats	2	N + P factorial (field)
	Potatoes	1	N + P factorial (field)
	Sugar beets	1	N + P factorial (field)
North Dakota	Potatoes	1	N + P factorial (field)
	Sugar beets	2	N + P factorial (field)
South Dakota	Sugar beets	1	N + P factorial (field)
Wisconsin	Corn	2	N source, degree of physical and chemical association of N + P in fertilizer (field)
	Oats	1	N source, degree of physical and chemical association of N + P in fertilizer (field)

previous soil treatment on phosphorus utilization was being studied, radioactive P_{32} was applied on at least part of the plots to permit assay of the fraction of the plant phosphorus derived from the fertilizer.

The radioactively labeled phosphate was supplied as superphosphate or concentrated superphosphate by the U.S. Department of Agriculture and the Atomic Energy Commission. The assay of plant samples for P_{32} content was done by the different laboratories according to the methods of MacKenzie and Dean (6), (7). The nonradioactive standard phosphate source for comparison is in all cases superphosphate or treble superphosphate unless otherwise specified.

Results and Discussion

1. Effect of Potassium on Phosphorus Utilization

The effect of potassium has been indeterminate or negative in experiments conducted in Illinois and Minnesota. Indiana experiments with corn showed a slight positive effect of potassium in two experiments on Crosby silt loam and Dana silty clay loam. These two soils had 220 and 530 pounds, respectively, of exchangeable potassium per acre. However, as indicated by the earlier work in Indiana (8) with Vigo soil (47 pounds exchangeable potassium per acre), potassium application had little effect on phosphorus utilization.

The effects noted in these experiments are summarized in table 1.

The data of table 1 show the lack of consistent effect of potassium on phosphorus utilization by corn, oats, and alfalfa. The two Indiana soils having 220 and 530 pounds of available potassium showed only a slight differential effect due to potassium treatment, as was observed by Robertson et al (8) concerning the Indiana experiment on Vigo soil in 1949.

Illinois experiments in which native soil potassium was sufficient for 99 percent and 87 percent of maximum yield in 1952 and

Table 1. Effect of Potassium on Utilization of Fertilizer Phosphate by Oats and Corn

State and Crop	Year	Soil Type	Potassium lbs. K_2O/A. Exch.	Added	Phosphorus lbs. P_2O_5/A. Avail.	Added	Time of Plant Sampling	% of Plant P from Fert. P	K & P
Ill. Oats	1952	Muscatine sil	222	50	55 (Bray #2)	40	maturity	27.8	27.8
Ill. Oats	1953	Muscatine sil	322	50	41 (Bray #2)	40	maturity	37.2	32.1
Ind. Corn	1950	Crosby sil	220	20	55 (Truog)	20	tassel	14.9	15.9*
Ind. Corn	1950	Dana sicl	530	20	80 (Truog)	20	tassel	14.6	15.9*
Minn. Corn									
(field 1)	1952	Nicollet sicl	200	20	46 (Bray #1)	20	18 in.	41.9	47.3
							72 in.	12.1	13.4
(field 2)	1952	Nicollet sicl	200	20	46 (Bray #1)	20	18 in.	23.8	33.0
							72 in.	11.9	15.8
Corn	(1952	Nicollet sicl	240	20	64 (Bray #1)	20	18 in.	33.1	44.5
Alfalfa	green-		240	20	64	20	12-15 in.	59.5	61.3
Oats	house)		240	20	64	20	heading	78.5	80.2

*Indiana values are for percentage recovery of applied phosphate, rather than percentage of plant phosphorus derived from the fertilizer.

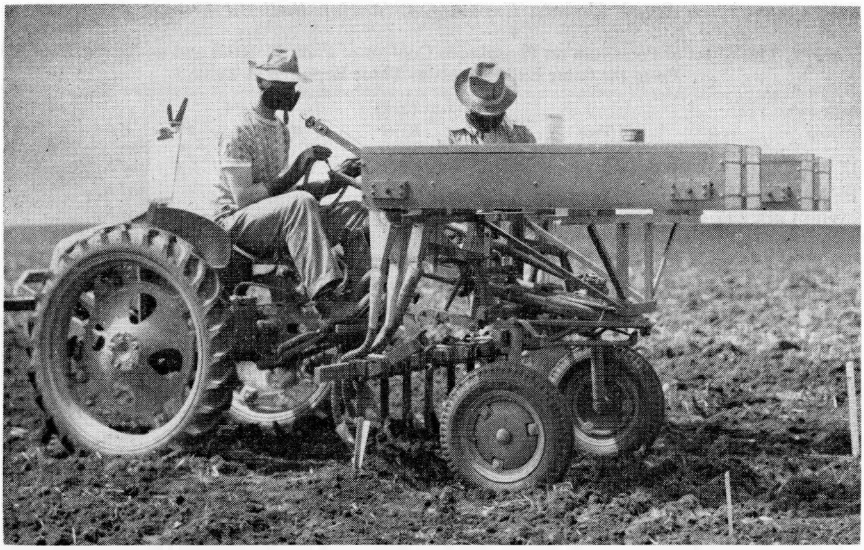

Figure 1. Combination fertilizer-seeder commonly used in conducting experiments with small grains and row crops. (See *Agronomy Journal* 43:575; Note by A. S. Hunter, Soil Scientist, Oregon Agricultural Experiment Station and USDA.)

1953, respectively, likewise showed no differential effect on phosphate utilization as a result of application of potassium fertilizer.

Minnesota field data on the Nicollet soil show a trend toward increased utilization of fertilizer phosphorus when potassium is added with the phosphate. This trend is not statistically significant. In the greenhouse experiment conducted at Minnesota, this increase was significant when the potassium was added mixed with the phosphate, but when applied separately on the opposite side of the row, no effect whatever was observed. This will be discussed more fully in section 4.

The effect of potassium on phosphorus content of various crops was likewise observed to be indeterminate or of small magnitude in most experiments in which this effect was measured. Some of the experiments resulted in yield responses to potassium, whereas others did not. The data concerning these two observations are summarized briefly in table 2.

2. Effect of Nitrogen on Phosphorus Utilization

The effect of nitrogen on phosphorus utilization from fertilizer and soil, on yields, and on phosphorus content of the crops is the more widely studied aspect of the general question under consideration. Perhaps this is because the effect (on phosphorus utilization) was first noted with nitrogen.

At least one experiment concerning nitrogen was conducted in each of the seven states cooperating, and as many as five were conducted in some states. Three of these are greenhouse experiments conducted

Table 2. The Effect of Potassium on Phosphorus Content of Plant Material and on Yields. Data Are From the Same Experiments as Those Reported in Table 1

State and Crop	Year	Soil Type	P Content (% P) P	P Content (% P) K+P*	Yield P	Yield K+P	Units	L.S.D. (.05)
Ill. Oats	1952	Muscatine sil	0.402	0.400	75.1	78.2	bu/A.	—
Ill. Oats	1953	Muscatine sil	0.368	0.387	79.7	82.5	bu/A.	—
Minn. Corn (1)	1952	Nicollet sicl	0.252	0.259	108.2	115.2	bu/A.	5.3
Minn. Corn (2)	1952	Nicollet sicl	0.220	0.214	82.7	83.3	bu/A.	N.S.
Minn. Corn	(1952	Nicollet sicl	0.244	0.237	7.8	7.7	g/pot	N.S.
Minn. Alfalfa	green-	Nicollet sicl	0.334	0.319†	11.9	13.1	g/pot	1.3
Minn. Oats	house)	Nicollet sicl	0.508	0.486	—	—	—	—

*All potassium applied with the phosphate fertilizer in the form of potassium chloride.
†Phosphorus content significantly different (.05 level) from that of plants treated with phosphate without potassium.

by Minnesota. The discussion of the nitrogen aspect will be divided into the two groups; **a**) close-sown crops (oats and alfalfa) and **b**) row crops (corn, potatoes, and sugar beets).

a) Close-sown crops. The field and greenhouse experiments concerned with oats and alfalfa were conducted in Illinois, Minnesota, Nebraska, and Wisconsin. The field experiments were all installed by means of combination fertilizer drills of the belt-feed type. The data reported are from trials in which the phosphate materials were placed at a depth of less than 3 inches with the seed.

The nitrogen was applied with the phosphate except in the Illinois and Nebraska experiments, in which the nitrogen was applied broadcast. In the greenhouse experiments at Minnesota, the nitrogen and phosphorus were mixed and applied to the top one-half inch of soil. The results reported are those obtained with superphosphate or treble superphosphate forms of phosphate and ammonium nitrate nitrogen, except that ammonium sulfate was used in Illinois.

As illustrated in the data of table 3, in all cases the use of nitrogen fertilizer has enhanced the utilization of the fertilizer phosphate. This, of course, results in a proportionate decrease in the utilization of soil phosphate and a decrease in the "A-value" (indicated available soil phosphorus level) as measured by the tagged phosphorus procedure.

This phenomenon can be made use of in two different directions, depending on circumstances. In some soils fertilizer phosphate is rapidly transformed into relatively unavailable forms. In such soils the application of the crop's required quantity of phosphate with nitrogenous fertilizer would greatly increase the economy of the phosphate application. In other soils, where an early starter effect only is required for the crop and the bulk of the phosphate requirements are met by the soil, a small localized application not necessarily accompanied by nitrogen would be the most economical method of application.

Table 4 gives the observations on yields and phosphorus contents of the crops pertinent to the experiments reported in table 3.

The data of table 4 indicate the effect of nitrogen on total phosphorus content of the crop to be indeterminate in the alfalfa and oat crops. The oat experiment conducted at Minnesota showed a significant decrease in phosphorus content due to nitrogen application. The alfalfa experiment at Minnesota and one oat experiment at Illinois and one at Nebraska showed slight increases, but the other experiments indicated decreases.

In the alfalfa experiment at Minnesota, a nearly significant increase in phosphorus content of the crop was accompanied by significant decrease in yield. In all other cases a slight yield increase resulted.

Table 3. Effect of Nitrogen Fertilizer on the Utilization of Fertilizer Phosphate by Oats and Alfalfa

State, Soil Type, and Crop	Year	Phosphorus as P_2O_5 Available lbs/A.	Phosphorus as P_2O_5 Added lbs/A.	Nitrogen Added lbs/A.	Time of Sampling	% of Plant P from Fert. P	% of Plant P from Fert. N+P	L.S.D. (.05)
Ill., Muscatine sil, Oats	1952	55 (Bray #2)	40	30	maturity	27.8	31.5	——
	1953	41 (Bray #2)	40	30	maturity	32.1	35.3	——
Minn., Nicollet sicl, Oats (greenhouse)	1952	64 (Bray #1)	100	100	heading	78.5	100.1	9.5
Minn., Nicollet sicl, Alfalfa (greenhouse)	1952	64 (Bray #1)	100	100	12 in.	59.5	66.5	N.S.
Nebr., Tripp vfsal, Oats	1952*	22 (Bray #1)	40	80	dough	36.5	45.4	6.2
	1952†	25 (Bray #1)	40	80	dough	27.1	30.1	2.8
	1953‡	---- ---- ----	80	80	dough	23.0	34.1	6.7
Wis., Miami sil, Oats	1951	46-70 (Truog)	60	48	harvest	13.1	27.1	3.9

*Plots on a former 6-year rotation of alfalfa, alfalfa, alfalfa, potatoes, oats, sugar beets, no manure.
†Plots on a former rotation same as (*) except 12 T. manure applied per rotation since 1912.
‡Plots on a former 4-year rotation of barley-alfalfa, alfalfa, potatoes, sugar beets.

Table 4. Phosphorus Content and Yields of Crops Grown With and Without Nitrogen Fertilizer

State and Soil Type	Year	Crop	P Content (% P) P	P Content (% P) P+N	L.S.D. (.05)	Yield bu/A.* P	Yield bu/A.* P+N
Ill. Muscatine sil	1952	Oats	0.400	0.391	——	78.2	93.2
Ill. Muscatine sil	1953	Oats	0.387	0.409	——	82.5	86.6
Minn. Nicollet sicl (greenhouse)	1952	Oats	0.508	0.337	0.122	——	——
Minn. Nicollet sicl (greenhouse)	1952	Alfalfa	0.335	0.350	0.019	11.9*	10.3*
Neb. Tripp vfsal	1952	Oats†	0.353	0.334	N.S.	36.5	38.1
Neb. Tripp vfsal	1952	Oats‡	0.374	0.398	0.024	40.1	44.7
Neb. Tripp vfsal	1952	Oats§	0.420	0.380	0.025	41.0	44.0
Wis. Miami sil	1953	Oats	0.272	0.239	0.025	56.7	62.0

*Minnesota greenhouse yields expressed in grams per pot.
†Plot on a former rotation same as (*) except 12 T. manure applied per rotation since 1912.
‡Same rotation as above; 12 tons manure per acre applied every 6 years since 1912.
§Plots on a former 4-year rotation of barley-alfalfa, alfalfa, potatoes, sugar beets.

This would indicate that a positive yield response to nitrogen increases the total phosphorus removed per acre by a crop, but this effect sometimes occurs in spite of a decreased percentage of phosphorus content in the crop by the simple process of stimulating the production of total dry matter. Conversely, when a yield reduction takes place, the percentage of total phosphorus in the crop may increase. This is quite in agreement with the findings of Smith, Kapp, and Potts (9) in a study on winter wheat in Texas and of Domby, Stelly, and Sell (2) in a study of winter oats in Georgia.

b) Row crops. Corn, potatoes, and sugar beets were used in various field experiments and in one greenhouse study to further evaluate the effect of nitrogen on phosphorus utilization. Three states worked with corn, two with potatoes, and three with sugar beets. The technique in all cases (except Nebraska experiments, in which the phosphate was broadcast) was to apply the fertilizer materials in admixture at about the time of planting.

Here again the use of phosphate tagged with P_{32} made possible the assay of fertilizer-derived phosphorus in the plant and the evaluation of nitrogen effects on fertilizer phosphorus uptake. The effect of nitrogen on utilization of phosphorus by row crops in the various experiments is summarized in table 5.

As may be seen from table 5, a marked increase in utilization of fertilizer phosphorus resulted from the application of nitrogen with the phosphate in all experiments except those conducted in Nebraska.

In the three experiments with oats conducted in Nebraska (table 3), however, positive responses were obtained. The reason for this is not completely clear, but several possible explanations are seen.

Two of the exceptions occurred on soil of long-time manured rotations, with available nitrogen well dispersed in the plow layer. Perhaps the most likely explanation, however, is the fact that the phosphate was broadcast in these experiments, whereas in all others it was banded. Furthermore, both potatoes and sugar beets have much longer growth periods than oats and as such would have more opportunity to obtain their phosphorus from sources other than the fertilizer.

This, in itself, may not explain why these crops failed to respond in Nebraska and responded so markedly in all other states. Nevertheless, this factor, combined with that of a very friable soil with nitrogen well disseminated in the plow layer and the fact that phosphate was broadcast rather than banded, might be conducive to lower fertilizer phosphorus utilization or at least utilization less affected by the use of nitrogen in conjunction with the phosphorus.

Increased phosphorus utilization resulting from nitrogen application ranges from 6.4 percent in one Nebraska experiment with sugar beets to 220 percent in the experiment with potatoes conducted in North Dakota. Most of these values are for the latest sampling date or the final harvest. In many cases early season utilization was much greater than late season, making the consideration of nitrogen usage in intimate mixture with phosphorus even more important under soil and crop conditions where early rapid uptake of phosphate is highly important.

The effect of nitrogen applications on phosphorus content of row crops was observed in the above experiments. The summarized data on these observations are reported in table 6. Leaves and petioles of sugar beets and potatoes were sampled, and the above-ground plant parts of corn were used for analysis.

As is the case with the close-sown crops (oats and alfalfa) no well-defined trend exists in the relationship of nitrogen applications to percent phosphorus in the crop. In some instances marked reductions in phosphate content occurred with increasing nitrogen, but a few rather definite increases also occurred.

3. Effect of Nitrogen Source and Rate of Application

There has been indication at times that some nitrogen sources are superior to others in inducing greater utilization of fertilizer phosphate. However, no clear-cut picture has evolved up to this time,

Table 5. The Effect of Nitrogen on the Utilization of Fertilizer Phosphate by Corn, Potatoes, and Sugar Beets

		Phosphorus as P_2O_5		Nitrogen	Stage of	% of Plant P from Fertilizer*	
		Available	Added	Added	Plant		
State and Crop	Soil Type	(lbs/A.)	(lbs/A.)	(lbs/A.)	Sampling	P	P+N
Ind. Corn	Crosby sil	55 (Truog)	20	5	tassel	9.3	14.9
Ind. Corn	Dana sicl	80 (Truog)	20	5	tassel	9.6	14.6
Minn. Corn (1)	Nicollet sicl	20 (Bray #1)	20	20	18 in.	41.9	57.6
					72 in.	12.1	20.3
Minn. Corn (2)	Nicollet sicl	20 (Bray #1)	20	20	18 in.	23.8	48.5
					72 in.	11.9	21.4
Minn. Corn	Nicollet sicl (greenhouse)	20 (Bray #1)	100	100	18 in.	33.1	55.0
Neb. Potatoes†	Tripp vfsal	164 (A-Value)	40	40	Sept. 4	19.7	17.9
Neb. Potatoes‡	Tripp vfsal	152 (A-Value)	40	40	Sept. 4	21.5	19.1
Neb. S. Beets†	Tripp vfsal	43 (A-Value)	40	80	Aug. 4	49.9	53.1
Neb. S. Beets‡	Tripp vfsal	137 (A-Value)	40	80	Aug. 4	24.4	23.9
N. Dak. Potatoes	Williams lo	490 (A-Value)	30	100	Sept. 10	6.1	19.5
N. Dak. S. Beets	Williams lo	74 (A-Value)	50	100	Sept. 24	44.0	62.7
N. Dak. S. Beets	Huff lo	329 (A-Value)	50	100	Sept. 25	25.5	47.5
S. Dak. S. Beets	Beotia sil	312 (A-Value)	40	80	Aug. 12	11.9	21.7
Wis. Corn§	Miami sil	80 (Truog)	18	13	silking	6.4	11.7

*Indiana experiments report percentage recovery of fertilizer P.
†Rotation 63—No manure.
‡Rotation 63B—Manure at 12 T/A every 6 years, 1914-1941.
§No nitrogen check was used in this experiment, so the data given are for nitrogen applied separately, and with the phosphorus, in the columns labeled "P" and "P+N," respectively; 100 pounds N also side-dressed later.

and some work done at Wisconsin, Indiana, and Nebraska is reported in an effort to clarify this situation.

As indicated in table 7, very little effect of difference in carrier was observed. There is a trend for the sodium nitrate values to be a little lower than those of the other carriers, both at the earliest and latest sampling date. Urea values also are apparently a little lower than those for ammonium nitrate and ammonium sulfate.

Wisconsin results with oats in 1951, using various formulations, indicated considerable difference may exist between the efficacy of various carriers. However, the effects are confounded with source of phosphate and degree of chemical and physical association of N and P in the formulations. For the data on this work refer to table 10.

The effect of rate of nitrogen application is indicated by experiments conducted in Indiana and

Table 6. The Influence of Nitrogen Applications on the Phosphorus Content of Row Crops

State	Crop	P Content (% P) P	P+N	Stage of Growth Sampled, or Date
Minn.	Corn	0.252	0.256	6 ft.
Minn.	Corn	0.221	0.216	6 ft.
Minn.	Corn*	0.245	0.221	18 in.
Neb.	Potatoes†	0.213	0.220	Sept. 4
Neb.	Potatoes‡	0.184	0.185	Sept. 4
Neb.	S. Beets*	0.174	0.200	Aug. 4
Neb.	S. Beets†	0.229	0.219	Aug. 4
N. Dak.	Potatoes	0.330	0.325	Sept. 10
N. Dak.	S. Beets	0.310	0.251	Sept. 24
N. Dak.	S. Beets	0.398	0.295	Oct. 9
N. Dak.	S. Beets	0.298	0.303	Sept. 25
N. Dak.	S. Beets	0.275	0.268	Sept. 27 (whole tops)
S. Dak.	S. Beets	0.332	0.306	Aug. 12
Wis.	Corn	0.251	0.226	Silking

*Greenhouse experiment.
†Rotation 63—No manure.
‡Rotation 63B—Manured.

Table 7. Effect of Nitrogen Source on Recovery of Applied Fertilizer Phosphorus by Corn in Indiana (1950)

Nitrogen Source	Fertilizer Applied lbs/A. N	P_2O_5*	Fertilizer P Recovered (%) June 28†	July 22	Soil Type
None	0	20	3.4	9.3	Crosby sil
			8.5	9.6	Dana sicl
Ammonium sulfate	5	20	3.8	14.9	Crosby sil
			4.0	14.6	Dana sicl
Ammonium nitrate	5	20	5.3	13.2	Crosby sil
			3.4	11.3	Dana sicl
Sodium nitrate	5	20	3.7	9.9	Crosby sil
			2.1	12.1	Dana sicl
Urea	5	20	4.8	11.7	Crosby sil
			3.4	12.3	Dana sicl

*All phosphate was applied as 20% superphosphate in one band at seed level at planting time.
†Corn was approximately 28 inches tall on June 28 and 80 inches on July 22.

Table 8. The Effect of Rate of Nitrogen Application and of Phosphate Source on Recovery of Fertilizer Phosphate and Early Growth Rate of Corn in Indiana

Phosphorus as P_2O_5 Applied (lbs/A.)	Nitrogen Applied (lbs/A.)	Phosphate Source	Soil	Fertilizer P Recovered (%)	Plant Height June 28 (in.)
20	0	20%	Crosby	9.3	55.9
20	0	super	Dana	9.6	66.6
20	5	phosphate	Crosby	14.8	62.4
20	5		Dana	14.6	70.0
20	10		Crosby	16.9	63.4
20	10		Dana	20.0	68.6
20	0	dical-	Crosby	3.2	47.6
20	0	cium	Dana	5.9	60.4
20	5	phosphate	Crosby	7.0	61.4
20	5		Dana	7.0	62.4
20	10		Crosby	7.8	60.4
20	10		Dana	11.3	66.2
20	0	45%	Crosby	10.8	57.6
20	0	superphos-	Dana	10.4	64.8
20	5	phate	Crosby	15.9	64.8
20	5		Dana	14.9	70.8

Nebraska. The materials were applied as starter fertilizers on corn, therefore the effect on early growth is noteworthy and is included. These results are given in tables 8 and 9.

Table 9. The Effect of Rate of Nitrogen Application on Utilization of Phosphorus in Treble Superphosphate by Oats in Nebraska (Tripp vfsal)

Nitrogen Applied (lbs/A.)	Plant P from Fertilizer (%)*	Fertilizer P Recovered (%)*
0	28.9	7.8
40	32.8	8.9
80	36.5	9.1

*The values given are averages for three experiments, two of which were conducted in 1952 (40 lb. P_2O_5 level labeled) and one in 1953 (80 lb. P_2O_5 level labeled).

From the data of tables 8 and 9 it appears that, with the crops indicated and at the levels of nitrogen used in these experiments, increased nitrogen application resulted in increased utilization of fertilizer phosphate. However, some data obtained in Nebraska on sugar beets and potatoes indicate that, especialy in heavily manured soils, increased absorption of phosphate is not clearly effected by band application of nitrogen when the phosphatic materials were broadcast (see table 10).

There are at least three possible explanations for the increased utilization of fertilizer phosphorus as a result of concomitant nitrogen application. There no doubt are circumstances when only one of these is operative, and others when all of these may exert their influence. No attempt is made here to evaluate the three but only to present the explanations and the impressions, when given, of the various contributing workers.

The first possibility is that of increased solubility of the phosphatic materials. This is effected by either a pH change by the nitrogen carrier or a mutual solubility enhancement effected by contact of the two materials. Mutual solubility is similar to the formation of eutectic mixtures of metals to give alloys or of two organic chemicals to form solutions at temperatures below the melting point of either. The Wisconsin workers believe that increased solubility of phosphate played an important role in their experiments.

Robertson et al (8) state that "physiological and chemical interactions of plants and soil account for the ammonium sulfate effects" in explaining the increased uptake of phosphorus when the nitrogen and phosphorus application is in a mixture rather than separate materials. The nitrogen was supplied as ammonium sulfate. Jacob and Hill (4) state that the solubility of phosphate may be affected by the presence of other salts. For example, the water solubility of dicalcium phosphate is enhanced several

Table 10. Effect of Degree of Physical and Chemical Association of N and P in Fertilizers on Utilization of Fertilizer Phosphorus

State	Crop	Fertilizer	Source of P	N-P Association	Plant P Derived from Fertilizer(%)	Recovery of Applied P(%)	Soil
Ind.	Corn	5-20-0	20% super-phosphate	100% phys.	—	14.9	Crosby sil
		5-20-0	20% super	none	—	6.6	Crosby sil
		5-20-0	20% super	100% phys.	—	14.6	Dana sicl
		5-20-0	20% super	none	—	8.5	Dana sicl
		5-20-0	45% treble super	100% phys.	—	15.9	Crosby sil
		5-20-0	45% treble super	none	—	7.8	Crosby sil
		5-20-0	45% treble super	100% phys.	—	14.9	Dana sicl
		5-20-0	45% treble super	none	—	10.4	Dana sicl
Minn. (green-house)	Corn	100-100-0	20% super	100% phys.	55.0	—	Nicollet sicl
		100-100-0	20% super	none	40.1	—	Nicollet sicl
		100-100-0	20% super	100% phys.	51.7	—	Nicollet sicl
		100-100-0	20% super	none	33.9	—	Nicollet sicl
Neb.	Beets*	80-40-0	45% super	none	53.1	—	Tripp vfsal
	Beets†	80-40-0	45% super	none	23.9	—	Tripp vfsal
	Potatoes*	40-40-0	45% super	none	17.9	—	Tripp vfsal
	Potatoes†	40-40-0	45% super	none	19.1	—	Tripp vfsal
Wis.	Oats	0-60-60	20% super	none	13.1	6.3	Miami sil
		48-60-60	20% super	100% phys.	27.1	12.6	Miami sil
		48-60-60	ammon. super	25% chem.	25.1	10.7	Miami sil
		48-60-60	monoammon. phosphate	25% chem.	31.6	13.5	Miami sil
		48-60-60	dicalcium phosphate	100% phys.	13.0	6.9	Miami sil
		48-60-60	17-22-00 (nitric phos)	85% chem.	18.0	7.7	Miami sil
		48-60-60	12-33-0 (nitric phos)	38% chem.	22.7	10.9	Miami sil
	Corn	13-18-18	20% super	100% phys.	11.7‡	16.7	Miami sil
		13-18-18	20% super	none	6.4‡	10.3	Miami sil
		13-18-18	17-22-0 (nitric phos)	100% chem.	3.8‡	6.1	Miami sil
		13-18-18	12-33-0 (nitric phos)	47% chem.	7.1‡	11.6	Miami sil

*Rotation 63—No manure.
†Rotation 63B—Manured.
‡Recovery calculated at maturity.

fold by the presence of ammonium nitrate.

The second possibility is that the effect of nitrogen on root distribution is great enough to partly control the area of uptake of phosphorus. The response of root growth to nitrogen distribution in the soil is quite well established, and since the same roots take part in absorption of all nutrients, it is logical to assume that phosphorus uptake is approximately proportional to root distribution in the three dimensions. The Indiana workers believe that root distribution was one of the major factors in their experiments.

The third possibility is in part related to the second. If an increased growth rate results from nitrogen increases, it can be assumed that roots as well as tops are stimulated.

When this root stimulation occurs in the band of fertilizer-enriched soil, a greater concentration gradient will exist between the phosphorus level in the root and that in the band than between the phosphorus level in the root and that in the rest of the soil. Even if diffusion is only one of the forces active in nutrient uptake, greater phosphate uptake will result in this soil band because of the higher diffusion rate. The Fick diffusion law has also been used by Hammond, Black, and Norman (3) to explain differential fertilizer response of corn and soybeans.

Whatever the mechanism, the effect is real and of practical economic importance.

4. Effect of Degree of Physical and Chemical Association of Nitrogen and Phosphorus on Fertilizer Phosphorus Utilization

Among several efforts to evaluate factors influencing the efficacy of nitrogen applications in increasing phosphorus utilization, the degrees of physical and chemical association of the nitrogen and phosphorus carriers have been studied by Wisconsin, Indiana, and Minnesota workers.

The varying degrees of chemical association in materials used in experiments conducted in Wisconsin were attained by using superphospate, ammoniated superphosphate, monoammonium phosphate, dicalcium phosphate, and two nitric phosphates, 12-33-0 and 17-22-0, as basic materials. Ammonium nitrate and muriate of potash were added to arrive at a formulation of 9.6-12-12.

All of these materials were applied at the rate of 500 pounds per acre with oat seed in the oat experiment. An over-all check, nitrogen check, and phosphorus check were also included in the treatments. In the Wisconsin corn experiment, starter fertilizers of an 8.8-12-12 formulation were drilled 2.5 inches to the side of the row and 1 inch below seed level.

In the Indiana and Minnesota experiments, physical association was studied by placing the N and P carriers on opposite sides of the row, or together on one side. The Nebraska comparison is of an unmanured soil (rotation 63) with a manured soil (rotation 63B). The available nitrogen supply was good on the unmanured soil and excellent on the manured soil in the total plow layer in addition to being present in a localized band in both cases. The phosphorus was applied broadcast in these Nebraska experiments. A green manure crop of alfalfa was plowed under before planting on both rotations. Some of the data from these experiments are reported in table 10.

The Wisconsin experiment on corn was conducted as a split plot type, with half of each plot receiving 10 tons of manure per acre 1 month before planting. The manure had no significant effect on the fertilizer sources as they influenced phosphorus utilization but did advance by 5 days the peak period of phosphorus uptake. The apparent inconsistency with Nebraska results with manure may be in a large part due to the lack of opportunity for decomposion and dissemination of nutrients from the manure throughout the soil in the case of the Wisconsin experiment.

A review of the data of table 10 indicates that the utilization of fertilizer phosphorus is related to both the degree of physical association of nitrogen band phosphorus and the water solubility of the phosphatic material. The increases in phosphorus recovery observed in the Indiana experiment ranged from 43 to 126 percent as a result of 100 percent physical association of nitrogen and phosphorus as compared to no association. Minnesota results indicated 35 to 50 percent increases and Wisconsin showed approximately 100 percent increase.

The dicalcium phosphate, with only 5 percent water soluble P_2O_5, provided no more phosphorus to the crop when 100 percent physically associated with nitrogen than the superphosphate with complete dissassociation. The percentages of fertilizer phosphorus recovered in the crop of the Wisconsin oats experiment fall into two groups. The superphosphate with nitrogen applied separately, the dicalcium phosphate, and the 17-22-0 are significantly lower than the other four sources. The low recovery in these three cases is believed to be related to the low solubility of the P_2O_5 in the materials when nitrogen is present, or, in the case of superphosphate alone, to the lack of nitrogen in intimate mixture.

5. Effect of Nitrogen on Seasonal Distribution of Fertilizer Phosphorus Utilization

In the course of these investigations, a progressive decrease in percentage of plant phosphorus derived from the fertilizer as the seasons advanced was observed in all cases. In spite of this, however, percentage recovery of applied phosphate increased as the seasons progressed. Some data illustrating these two points are presented in table 11.

The phosphate recovery values at final sampling dates range to 392 percent of that at first sampling in the Indiana experiment on Crosby silt loam. This indicates progressive utilization of the fertilizer phosphate, even though the samples were taken only 24 days apart.

On the other hand, with two exceptions (the Wisconsin results

Table 11. Seasonal Changes in Fertilizer Phosphorus Recovery and in Crop Content of Fertilizer Phosphorus

State	Soil	Crop	Nutrients Applied P_2O_5 (lbs/A.)	N (lbs/A.)	Phosphorus Utilization Sampling Numbers* 1st	2nd	3rd	4th
					Recovery of fertilizer P (%)			
Ind.	Crosby	Corn	20	5	3.8	11.1	14.9	
	Dana	Corn	20	5	4.0	8.6	14.6	
Wis.	Miami	Oats†	60	48			12.6	
		Oats‡	60	48			13.5	
					Plant P from fertilizer (%)			
Neb.	Tripp	Oats§	80	0	54.2	28.9		
			80	40	58.9	32.8		
			80	80	58.6	36.5		
S. D.	Beotia	S. beets	40	0	23.4	18.7	17.6	11.9
			40	80	27.4	36.1	34.2	21.7
Wis.	Miami	Oats†	60	48	33.2	45.7	27.1	
		Oats‡	60	48	51.7	45.6	31.6	

*Crops were sampled as follows: corn in Indiana on June 29, July 11, and July 22; oats in Wisconsin on May 24, June 19, and August 9 (harvest); oats in Nebraska just before heading and in the late dough stage; and sugar beets in South Dakota on July 1, 15, 30, and August 12.
†Nitrogen supplied wholly as ammonium nitrate; phosphorus as 20% superphosphate.
‡Nitrogen supplied as ammonium nitrate and monoammonium phosphate; phosphorus as monoammonium phosphate.
§Values for each time and nitrogen level are averages of three experiments.

with superphosphate on oats and the South Dakota results with high nitrogen and treble superphosphate on sugar beets), the values for percent plant phosphorus derived from the fertilizer decline progressively with time. This situation results from the fact that, although the crops are still feeding on the fertilizer phosphate, the fertilizer plays a progressively smaller role in the total nutrition of the plant after a certain peak period is passed (see figure 2).

Root extension and total soil volume exploited by the plant increase rapidly after the seedling stage unless some factor such as impeded drainage, restricted aeration, or strongly localized soil fertility cause an abnormal growth situation. Apparently the 80-pound nitrogen application to sugar beets in the South Dakota experiment was sufficient to temporarily cause this localized nitrogen fertility situation. After the second sampling, however, the percent plant phosphorus from the fertilizer declined steadily.

A Wisconsin experiment with corn undertook a rather intensive study of the time-distribution of fertilizer phosphorus utilization. Four conditions of fertilization, all at the same level but with different carriers of phosphate with physical separation of the nitrogen and phosphorus carriers, were used on corn. The corn was sampled at seven dates after planting and the percentage of plant phosphorus derived from the fertilizer determined under each treatment at each date. The results of this work are presented graphically in figure 2.

Figure 2 shows clearly that with corn sampled at 15, 20, 25, 30, 35, 63, and 117 days after planting, there is a sharp increase in plant phosphorus derived from the fertilizers in the early growth stages, followed by a progressive decline

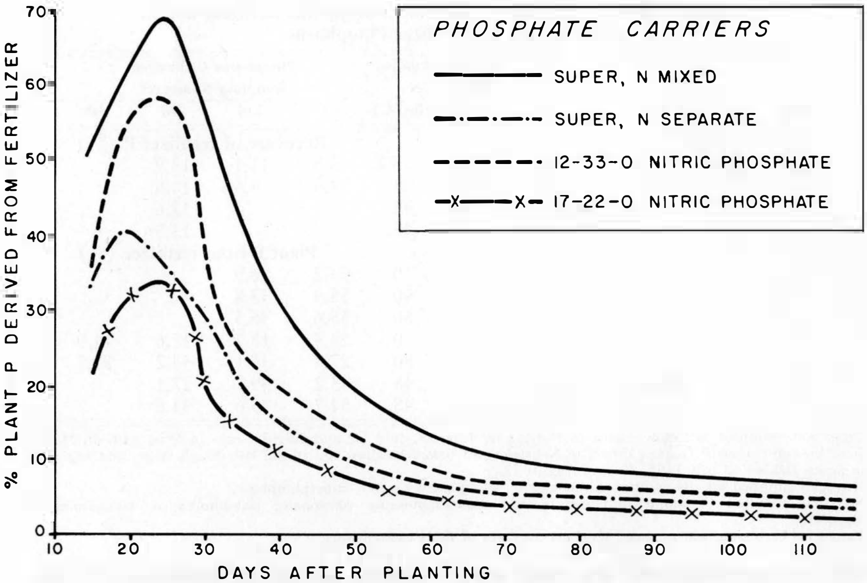

Figure 2. Effect of phosphate carrier and nitrogen association on the time of utilization of fertilizer phosphate by corn (Wisconsin)

thereafter. These results were obtained on a Miami silt loam soil with fairly friable subsoil and very adequate depth distribution of available phosphorus.

The available phosphorus by the Truog method increased with depth until it reached a value of about 60 parts per million at a depth of 3 to 4 feet. This indicates that, aside from the two exceptions noted earlier, the values reported in table 10 were all obtained from crop sampling procedures begun at or after the peak in phosphate absorption from the fertilizer.

Figure 2 also shows very graphically the low utilization values resulting from the use of the nitric phosphate 17-22-0 or from separating the nitrogen application from the phosphorus in the case of superphosphate.

Conclusions

Increased available potassium in the soil attained by the use of potassium fertilizers had little effect on fertilizer phosphorus utilization by crops of the North Central Region. Initial exchangeable soil potassium appeared to have no effect on the recovery of fertilizer phosphorus as measured by oats, corn, and alfalfa. Application of potassium with phosphorus in the fertilizer band likewise had no sigificant effect on the phosphorus content of oats and corn. However, potassium applied with phosphate in a broadcast application for alfalfa significantly lowered the phosphorus content of alfalfa in a Minnesota trial.

Addition of fertilizer nitrogen in the area of phosphate application greatly enhanced the utilization of fertilizer phosphorus, both as measured by percentage of plant phosphorus derived from the fertilizer and by recovery of applied phosphorus. The increases in percentage of plant phosphorus from the fertilizer resulting from concomitant nitrogen application to close-sown crops ranged from 10 percent in an Illinois experiment to 107 percent in a Wisconsin experiment. The increases with row crops ranged from 6.4 percent in a broadcast application in Nebraska to 220 percent with banded application in a North Dakota experiment. These values are in comparison with no nitrogen application or with the nitrogen applied separately.

Use of nitrogen with phosphorus significantly reduced phosphorus concentration in crops in some instances and appeared to increase it in a few cases. Total phosphorus removed per acre may frequently be increased by increased total yield, in spite of a decreased phosphorus content of the crop as percent of dry matter. The addition of nitrogen fertilizer, by increasing the utilization of fertilizer phosphorus, results in reduced "A-values" (indicated available soil phosphorus levels) in proportion as the percentage plant phosphorus derived from the fertilizer increases.

The effect of nitrogen applications in increasing the utilization of fertilizer phosphate occurred with all nitrogen carriers observed. However, sodium nitrate was the least effective among the sources of nitrogen investigated.

The effect of increasing the rate of nitrogen application was in all cases to progressively increase the utilization of fertilizer phosphate. This effect can be used advantageously in soils that rapidly transform applied phosphorus to less readily available forms. It is recognized that the phenomenon may sometimes cause localization of roots in early growth stages, which may be a detriment to the crop in case of drought.

The nature of the phosphate carrier was observed in experiments conducted in Wisconsin to have some influence on the nitrogen efficacy in increasing phosphorus utilization. The phosphorus of nitric phosphates and dicalcium phosphate was utilized less than that of other carriers studied.

The effect of conjoined nitrogen and phosphorus application in increasing phosphorus utilization was especially important in the early growth stages of the crops studied. In some cases as much as 65 or 70 percent of the phosphorus in the crop was derived from the fertilizer early in the season, whereas later values dropped to 6 to 12 percent. Thus, the economy derived by application of nitrogen with the phosphorus in fertilizers is doubly important with those crops that absorb a large part of their phosphorus in early growth stages, such as the small grains.

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